The inventory, quantification and evaluation of soil sealing as a Desertification process

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1. Abstract

Within the wide range of processes that intervene in Desertification, soil sealing has become the most important and dynamic in some areas such as the littoral and pre-littoral shores of the Mediterranean Region. Desertification, a global environmental problem that affects about 40 per cent of the Earth's land, "leads to a persistent decline in economic productivity of useful biota related to land use or a production system" in which sealing intervenes by destroying irreversibly the plant productivity of soils.

To assess the real soil sealing dimensions, a spatial and temporal methodological procedure, using Geographical Information Systems techniques has been developed. As a first step, precise mapping of the sealed surfaces for the year 1991 and 2004 using high definition orthophotos were undertaken, and classified according to major types (communication networks, buildings, etc). Second, specific analytical procedures were developed based on (1) the application of landscape metrics such as sealed area by soil sealing type, and (2) the environmental impact by calculating the consumption of soil land capability with the soil sealing maps.

The above methodology has been applied to an intermediate region, "Camp de Turia", of 758 km2, the Autonomous Region of Valencia (SE Spain). Results show in both dates moderate rate of sealed surfaces (5.6% in 1991 and 6.6% in 2004), were the most important trends are the process intensification between 1991 and 2004. Also there has been an increase in losses of most fertile soils for agriculture production (consume of 6.6% and 7.5% of very high, high and moderate land capability soils in 1991 and in 2004 respectively).

The methodological approach using detailed and precise inventories of artificial sealing surfaces and specific indicators show the need to assess Desertification, even in very dynamic areas, as a way to evaluate the process both in time and space. Also, if applied regularly, would constitute an important tool for land evaluation, planning and management.

2. Introduction

Within the wide range of processes that intervene in Desertification "a condition of human-induced land degradation that occurs in arid, semiarid and dry sub-humid regions (P/ETP ranging from 0.05 to 0.65) and leads to a persistent decline in economic productivity (>15% of the potential) of useful biota related to a land use or a production system" (Katyal. J.C. and Vlek, 2000), soil sealing has become the most important and dynamic in some areas such as the littoral and pre-littoral shores of the Mediterranean Region (Plan Bleu, 2001). Sealing intervenes by destroying irreversibly the plant productivity of soils. Also, the soil sealing mechanism is directly related with the water cycle in both the quantity of water production, by the impediment to soil infiltration, and the loss of water quality, by the accumulation of pollutants on sealed surfaces runoff (Schueler, 1994).

Due to the awareness that soil sealing constitute a major global, including the Mediterranean region, problem, some research gaps have been identified. One of the most relevant is the need of precise data on the spatial extent as well as the development of specific indicators (EEA, 2002), related to the soil and water components.

The objective of this work is to provide a methodological frame work to proceed with detailed inventory of anthropogenic sealed surfaces, the spatial an temporal evaluation and distribution of the process and its relation with soil (agriculture) productivity.

The methodology has been applied to the Camp de Turia County (784 km2) in the Valencia Region, Spain. It is a typical Mediterranean transition area, with exogenous influence of the large city of Valencia and its metropolitan area. In the last fifty year period there has been an important socio-economic change in the area that has been reflected in land cover intensification and conversion processes (Pascual Aguilar, 2004).

Land cover intensification it has been produced with the transformation of traditional rain fed farming into irrigation citrus fields, whereas land cover conversion it has been produced with the transformation of agricultural land into residential areas, industrial and commercial surfaces and the enlargement of the communication network.

3. Methods

Implemented within a Geographical Information System (GIS) environment (Burrough and McDonnell, 1998), the methodoly has been structured in three major steps. First data sources identification and input into de GIS mainframe were undertaken. Two different types of sources have been used: (1) orthophotos for the years 1991 and 2004 at 1:5000 scale provided by regional authorities and (2) a digital soils land capability map (Antolin, 1998) which provides, among other edaphic and topographic properties, with five classes of agriculture feasibility of soils (1. Very high, 2. High, 3. Moderate, 4. Low and 5. Very low land capability).

The second step was the construction of the geometric (vector digitising of the soil sealing elements identified on the orthophotos) and semantic (attributes of the geometric features) databases. Feature extraction consisted on the conventional approach in aerial photograph interpretation (e.g. Taylor et al., 2000). Legend definition (semantic attributes) has followed a multilevel approach (Bossard et al., 2000) based on the typology of sealing surfaces. Three hierarchy levels have been determined. Level 1 identifies major typologies according to the sealing surfaces and their potential edaphic (and environmental) impact (1. Building-roofing surfaces, 2. Paved and compacted surfaces, 3. Quarrying-mining and dump sites, 4. Infrastructures); Level 2 presents a more detailed legend of the soil sealing major types identified in Level 1; whereas Level 3 offers specific properties of the sealing surfaces: in all 23 classes have been described in level 3 of which 14 are present in this study.

The third step is the development of an analytical framework that undertakes both spatial static (in one moment) comparison, or synchronic approach and temporal spatial analysis (diachronic comparison). The spatial and temporal identification of soil sealing surfaces are related first with its intrinsic dynamic of the process and second with the deterioration of the edaphic land capability properties of soils.

4. Results

Synthetic values of soil sealing (Table 1) show overall moderate rates of sealed surfaces (5.6% in 1991 and 6.6% in 2004), with an important average increase within the 13 year period of up to 14.4%. Agriculture land capability consumption is in both dates higher for agriculture soils (Very high, High and Moderate types), with relative values between 6.4% and 8.4% in 2004. Rates of increment of such soils are also intensive between both dates, ranging from 10.0% (very high land capability soils) to 16.4% (Moderate). Thus there has been an increase in losses of most fertile soils for agriculture production (consume of 6.6% and 7.5% of very high, high and moderate land capability soils in 1991 and in 2004 respectively) that is reflected in the sealed of 351.8 hectares of good quality agriculture land with an average relative increment of 12.4%.

Table 1 Synthetic absolute (hectares) and relative (percentage) values of soil sealing consumption by land capability types

Land Capability Surface			Soil sealing (1991)		Soil sealing (2004)		2004-1991	
Type	Ha	%	Ha	%	Ha	%	Ha	%
1: Very high	6958.3	9.2	405.4	5.8	445.7	6.4	40.4	10.0
2: High	22791.9	30.1	1493.7	6.6	1649.4	7.2	155.7	10.4
3: Moderate	13139.4	17.3	949.2	7.2	1104.9	8.4	155.7	16.4
4. Low	23990.6	31.6	1188.6	5.0	1432.3	6.0	243.7	20.5
5: Very low	8947.4	11.8	364.5	4.1	402.8	4.5	38.3	10.5
Totals	75827.6	100.0	4401.4	5.8	5035.2	6.6	633.8	14.4

Detailed results of soil sealing covers and land capability consumptions are shown from Table 1 to Table 5. Initial conditions presented in 1991 demonstrate the importance of the paved and compacted surfaces in the dynamics of the soil sealing process, with almost 70% of the total land covered by such categories. Of those, three classes are more incident on the territory: 2.1.3 (Secondary paved roads), 2.1.2 (Main roads) and 2.2.1 (Street networks and parking lots, mainly associated with concentrate buildings and medium-low density urbanized places). Such trend is repeated in the distribution mapped for the year 2004, with little changes occurred in both dates, except for the class 221 (Street networks and parking lots), which probably shows the importance of the introduction of asphalt to urban peripheries and the street concentration of new low density and isolated housing.

The second main group in importance is constituted by Building-roofing surfaces. In 1991, 24% of the space was sealed, in this order, by roofing classes: 1.1.1. Buildings in high density urban areas (the traditional settlements and their expansion edges), 1.1.2. Buildings in medium-low density urbanized areas (a new trend that intensifies since the last third of the 20th century) and 1.1.3. Isolated buildings.

Table 2 Absolute values (hectares) of land capability consumption by soil sealing in 1991

1991		Soil sealing type														
(ha)		111	112	113	121	211	212	213	214	215	221	311	411	415	432	Totals
Land Capability	1	51.9	10.6	16.4	12.2	0.0	29.7	237.2	4.8	1.5	34.9	0.0	6.2	0.0	0.0	405.4
	2	177.9	73.5	60.8	31.3	24.5	160.6	769.0	7.7	9.8	127.4	12.2	38.5	0.1	0.4	1493.7
	3	74.1	84.3	45.8	39.5	5.4	98.3	491.6	1.5	3.4	56.6	16.7	31.9	0.0	0.2	949.2
	4	93.2	171.3	38.1	9.6	0.8	76.7	657.5	5.0	2.2	39.7	46.8	47.6	0.0	0.0	1188.6
	5	56.2	8.4	5.7	3.6	0.3	23.2	150.8	0.8	0.1	31.1	81.2	3.2	0.0	0.0	364.5
Totals		453.3	348.1	166.7	96.2	31.0	388.4	2306.0	19.8	17.1	289.7	156.9	127.5	0.1	0.6	4401.4

Table 3 Absolute values (hectares) of land capability consumption by soil sealing in 2004

2004		Soil sealing type														
(ha)		111	112	113	121	211	212	213	214	215	221	311	411	415	432	Totals
Land Capability	1	54.8	11.1	16.7	13.9	0.0	29.7	237.2	4.8	1.5	64.0	0.1	8.5	0.0	3.6	445.7
	2	183.5	81.2	62.5	51.2	25.3	161.5	769.2	7.7	9.8	225.4	18.9	48.7	0.1	4.5	1649.4
	3	75.8	90.8	48.6	54.2	5.6	100.1	492.0	1.5	3.4	154.1	32.5	40.8	0.0	5.4	1104.9
	4	105.8	179.8	41.2	11.1	0.8	79.7	658.2	5.0	2.2	212.6	77.0	51.9	0.1	6.8	1432.3
	5	56.2	8.5	5.7	3.8	0.3	23.2	150.8	0.9	0.1	32.6	116.6	4.2	0.0	0.2	402.8
Totals		476.2	371.4	174.8	134.1	32.0	394.1	2307.3	19.8	17.1	688.7	245.0	154.0	0.3	20.4	5035.2

Table 4 Absolute differences (hectares) of land capability consumption between 2004 and 1991

2004-1991		Soil sealing type														
(ha)		111	112	113	121	211	212	213	214	215	221	311	411	415	432	Totals
Land Capability	1	2.8	0.5	0.3	1.7	0.0	0.0	0.0	0.0	0.0	29.0	0.1	2.2	0.0	3.6	40.4
	2	5.6	7.7	1.7	19.9	0.8	0.9	0.2	0.0	0.0	98.0	6.7	10.2	0.0	4.0	155.7
	3	1.8	6.5	2.8	14.6	0.3	1.8	0.4	0.0	0.0	97.5	15.9	8.9	0.0	5.2	155.7
	4	12.6	8.5	3.1	1.5	0.0	3.0	0.7	0.0	0.0	172.9	30.2	4.3	0.1	6.8	243.7
	5	0.0	0.1	0.1	0.1	0.0	0.0	0.0	0.0	0.0	1.5	35.4	0.9	0.0	0.2	38.3
Totals		22.9	23.3	8.0	37.9	1.0	5.7	1.3	0.0	0.0	398.9	88.2	26.5	0.2	19.8	633.8

Table 5 Relative differences (percentage) of land capability consumption between 2004 and 1991

2004-1991		Soil sealing type														
(%)		111	112	113	121	211	212	213	214	215	221	311	411	415	432	Totals
Land Capability	1	5.4	4.9	2.0	14.3	--	0.0	0.0	0.0	0.0	83.2	--	35.5	--	--	10.0
	2	3.1	10.5	2.8	63.6	3.1	0.6	0.0	0.0	0.0	76.9	54.7	26.5	0.0	953.7	10.4
	3	2.4	7.7	6.2	37.1	4.9	1.8	0.1	0.0	0.0	172.2	95.1	27.8	--	--	16.4
	4	13.6	4.9	8.2	15.9	0.0	3.9	0.1	0.0	0.0	435.0	64.5	9.0	--	--	20.5
	5	0.0	1.0	1.3	3.0	0.0	0.0	0.0	0.2	0.0	4.8	43.6	29.0	--	--	10.5
Totals		5.0	6.7	4.8	39.4	3.3	1.5	0.1	0.0	0.0	137.7	56.2	20.8	178.	3243.5	14.4

LAND CAPABILITY: 1. Very high; 2. High; 3. Moderate; 4. Low; 5. Very low.
SOIL SEALING TYPE:
1.1. Residential:**1.1.1**. Building in high density urban area; **1.1.2**. Building in medium-low density urbanized area; **1.1.3**. Isolated building.
1.2. Industrial-Commercial: **1.2.1**. Industrial-commercial concentrate building.
2.1. Communication networks: **2.1.1**. Speed motorway; **2.1.2**. Main road; **2.1.3**. Secondary paved road; **2.1.4**. Private roads and paths; **2.1.5**. Areas affected by main roads.
2.2. Urban structures: **2.2.1**. Street networks and parking lot.
3.1. Quarrying and mining: **3.1.1**. Open air quarrying.
4.1. Water infrastructures: **4.1.1**. Pool; **4.1.5**. Large tank.
4.3. Sport and leisure: **4.3.2**. Sport infrastructure.

Changes between 1991 and 2004 for buildings show a larger increment of the class 1.2.1 (Industrial and commercial buildings) of up to 39.4%, although percentages for the rest of the roofing types are also important, both 1.1.1 (Building in high density urban area) and 1.1.2 (Building in medium-low density urbanized area) types experienced considerable increments, 22.9 and 23.3% respectively.

The impact on the soil land capability of the above trends reflects that, although the occurrence of soil sealing until 1991 was important in the disappearance of agricultural land, the increments reflected in 2004 have produced, to an important extent, the disappearance of good productive soils, closely approaching the Desertification threshold, >15% of the potential productivity (Katyal. J.C. and Vlek, 2000).

The methodological structure based on GIS and using detailed and precise inventories of artificial sealing surfaces and specific indicators show the need to assess Desertification, even in very dynamic areas, as a way to evaluate the process both in time and space. Also, if applied regularly, would constitute an important tool for land evaluation, planning and management.

5. References

Antolín, C., 1998. El suelo como recurso natural en la Comunidad Valenciana. Generalitat Valenciana, Valencia.

Bossard, M., Feranec, J., Otahel, J., 2000. CORINE land cover technical guide –Addendum 2000. European Environment Agency, Copenhagen.

Burrough, P.A., McDonnell, R. A., 1998. Principles of Geographical Information Systems. Oxford University Press, Oxford.

EEA., 2002. Proceedings of the technical workshop on indicators for soil sealing. European Environment Agency, Copenhagen.

Katyal. J.C., Vlek, G.V., 2000. Desertification - Concept, Causes and Amelioration. ZEF-Discussion Papers on Development Policy No. 33, Center for Development Research (ZEF), Bonn.

Pascual Aguilar, J.A., 2004. Dinámica reciente de usos del suelo en el continuo metropolitano de Valencia. Cuadernos de Geografía, 76: 183-202.

Plan Bleu, 2001. Urbanisation in the Mediterranean region from 1950 to 1995. Centre d'Activités Régionales, Sophia Antipolis.

Schueler, T., 1994. The Importance of Imperviousness. Watershed Protection Techniques, 1 (3): 100-111.

Taylor, J. C., Brewer, T. R., Bird, A. C., 2000. Monitoring landscape change in the National Parks of England and Wales using photo interpretation and GIS. International Journal of Remote Sensing, 21: 2737-2752.

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